

2006 DOE Hydrogen, Fuel Cells & Infrastructure Technologies

Program Review Presentation

Startech Hydrogen Production



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Project ID#: PDP10

This presentation does not contain any proprietary or confidential information.

Overview

Timeline

- Start: October 04
- Phase 1 End: December 05
- Phase 2 End: December 06

Budget

- Phase 1: \$613,174
 - DOE Portion: \$490,539
 - Share Portion: \$122,635
- Phase 2: \$620,000
 - DOE Portion: \$496,000
 - Share Portion: \$124,000

Barriers

- C. Operation and Maintenance
- D. Feedstock Issues
- F. Control And Safety
- M. Impurities
- R. Testing and Analysis
- V. Feedstock Cost and Availability
- W. Capital Cost and Efficiency

Partner

Media and Process
Technology Inc.

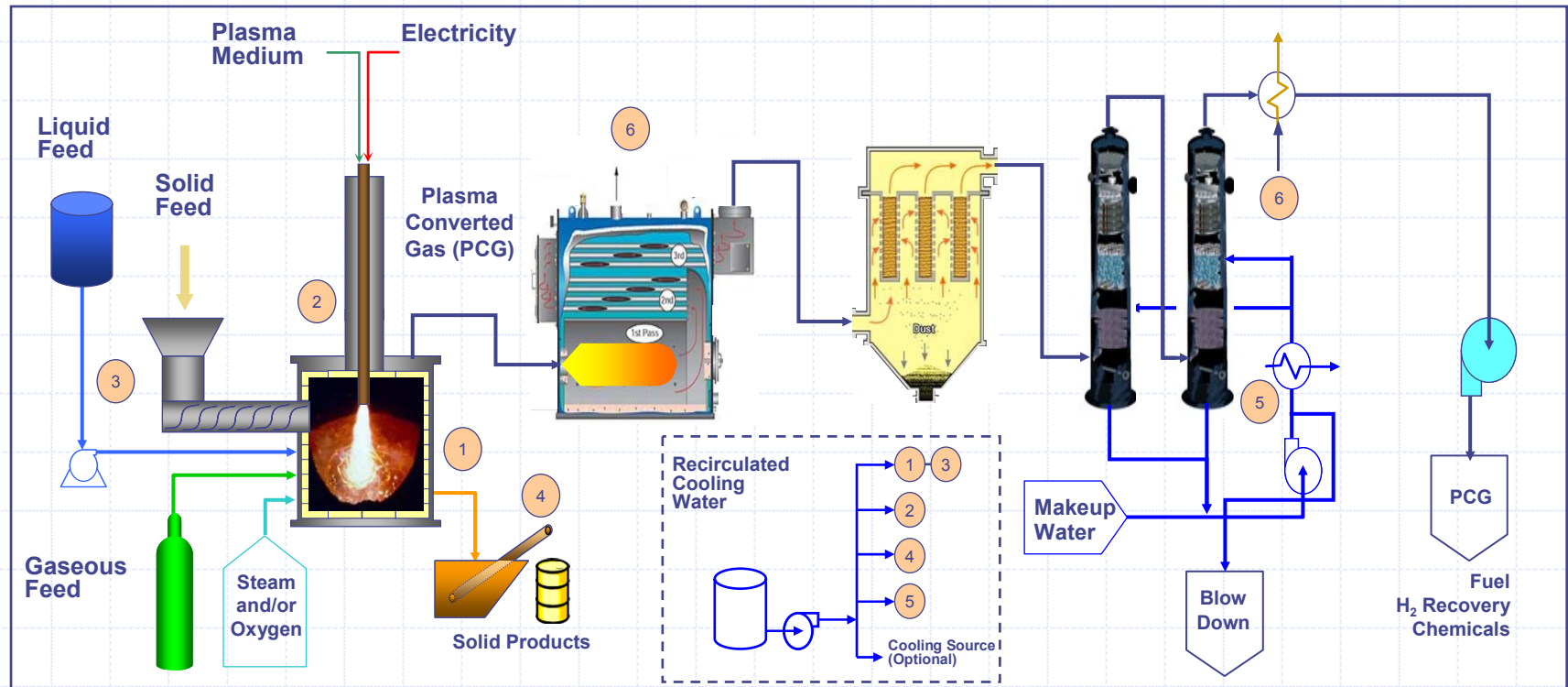
Project Objectives

- Field test integrated hydrogen production on a pilot scale using plasma gasification and ceramic supported carbon molecular sieve membrane hydrogen separation.
- Evaluate commercial viability and scalability through extended operation under representative conditions.
- Characterize the performance of the integrated Plasma Converter and StarCell™ Systems for hydrogen production and purification from abundant and inexpensive feedstocks.
- Compare integrated hydrogen production performance to conventional technologies and DOE benchmarks.
- Run pressure and temperature testing to baseline StarCell's performance.
- Determine the effect of process contaminants on the StarCell™ system.

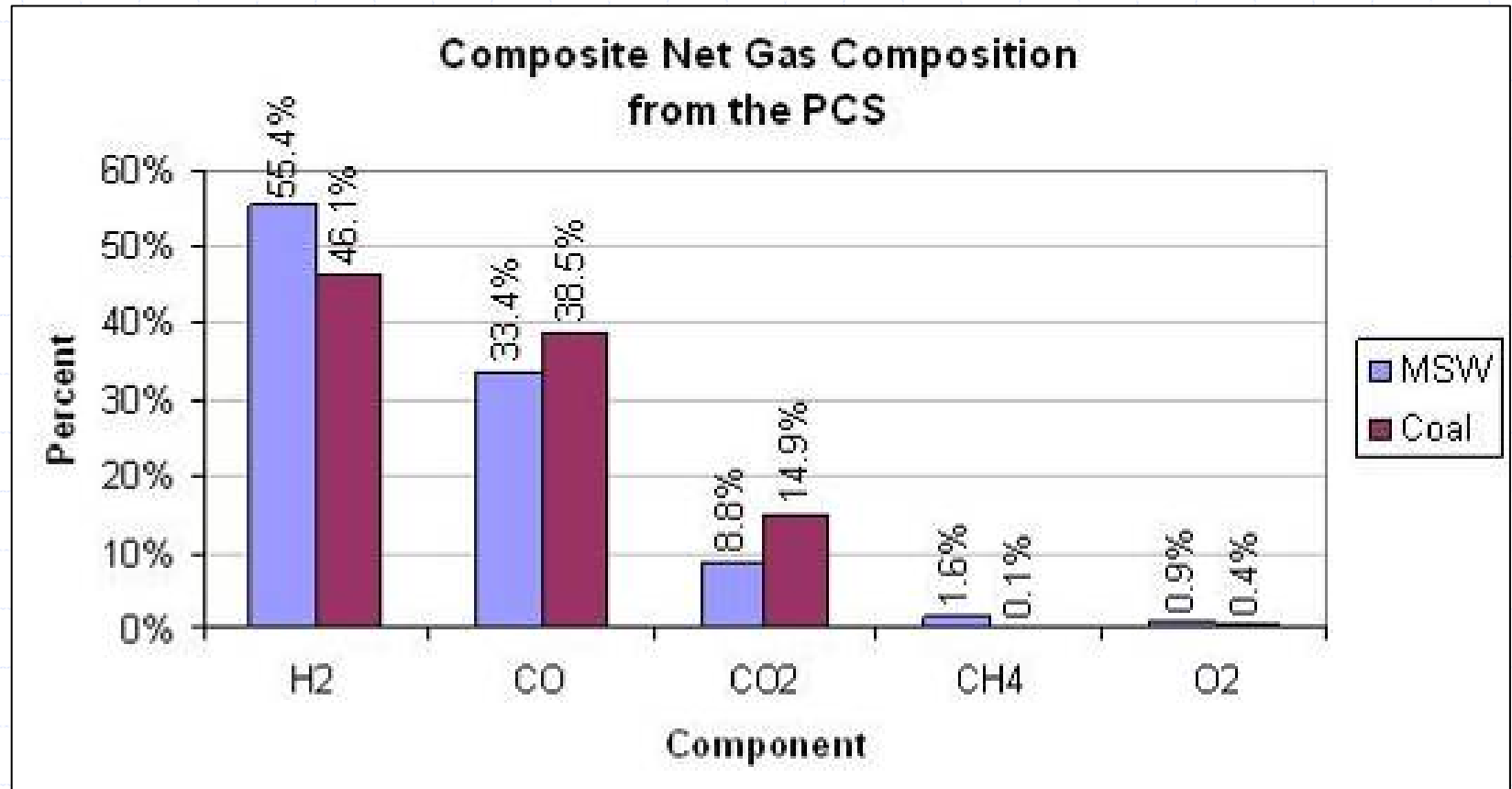
Analytical Approach

1. Utilize StarCell ceramic supported carbon molecular sieve membrane system to purify Hydrogen from a mixed Synthesis Gas.
2. Utilize Plasma Converter Gasification System to generate Hydrogen Rich Synthesis Gas.
3. Characterize plasma gasification and membrane separation as an integrated hydrogen production system.
4. Characterize and baseline integrated operation using MSW surrogate and coal as feedstocks.
5. Incorporate lessons learned

Plasma Converter System



Gas Composition Results



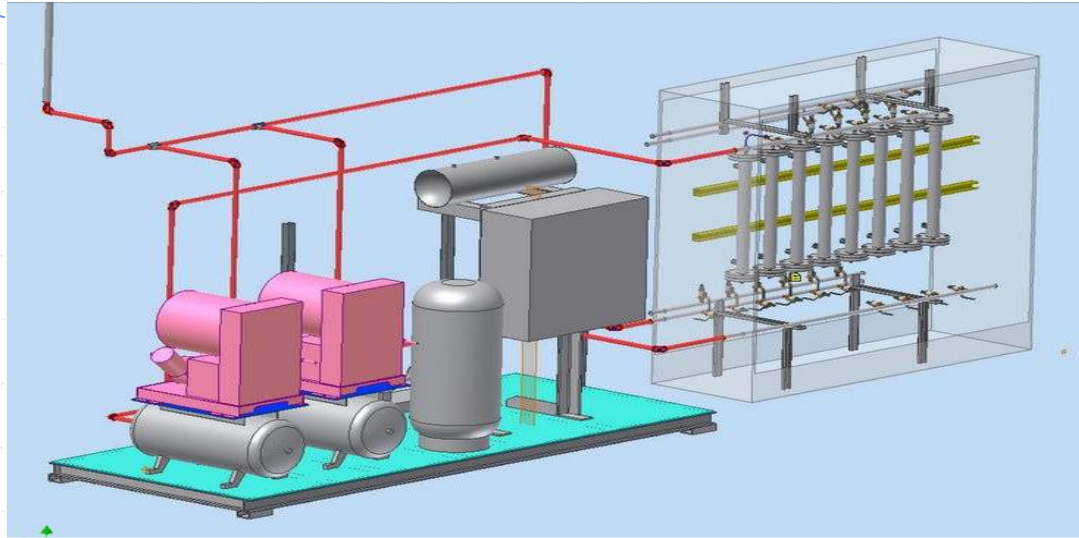
Gas Contaminant Results

Test Parameter	Coal Results Description	MSW Results Description
Siloxanes, HAP	Very Low. Almost all below the detection limit. Some detected but near detection limit. CS ₂ ~.077 mg/dscm, Flyer hit for Acetone.	Very Low to none detected on all. CS ₂ 7.9 mg/dscm.
Mercaptans	None detected	None detected for Mercaptan and all sulfur compounds except COS 22 mg/dscm and CS ₂ 0.004 mg/dscm
Heavy Metals (Ag, As, Ba, Cd, Cr, Hg, Pb, Se)	All metals were either in the non-detect or ug / dscm range (very low). Metals of particular concern with coal: Hg 0.8 ug/dscm, Pb 3.9 ug/dscm, Cr 2.0 ug/dscm, Cd 0.2 ug/dscm, Ba none detected.	All metals were either in the non-detect or ug / dscm range (very low). Metals of particular concern with coal: Hg 0.2 ug/dscm, Pb 1.2 ug/dscm, Cr 3.2 ug/dscm, Cd 0.2 ug/dscm, Ba none detected.
SO₂, SO₃	None detected	None detected
Permanent Gases	Almost no non-methane hydrocarbons. Very good for membrane performance. 470 ppm CH ₄ , ~5 ppm of Acetylene and Ethene. Non-detect on all others.	No non-methane hydrocarbons detected. Very good for membrane performance. ~1% CH ₄ .

Gas Contaminant Results

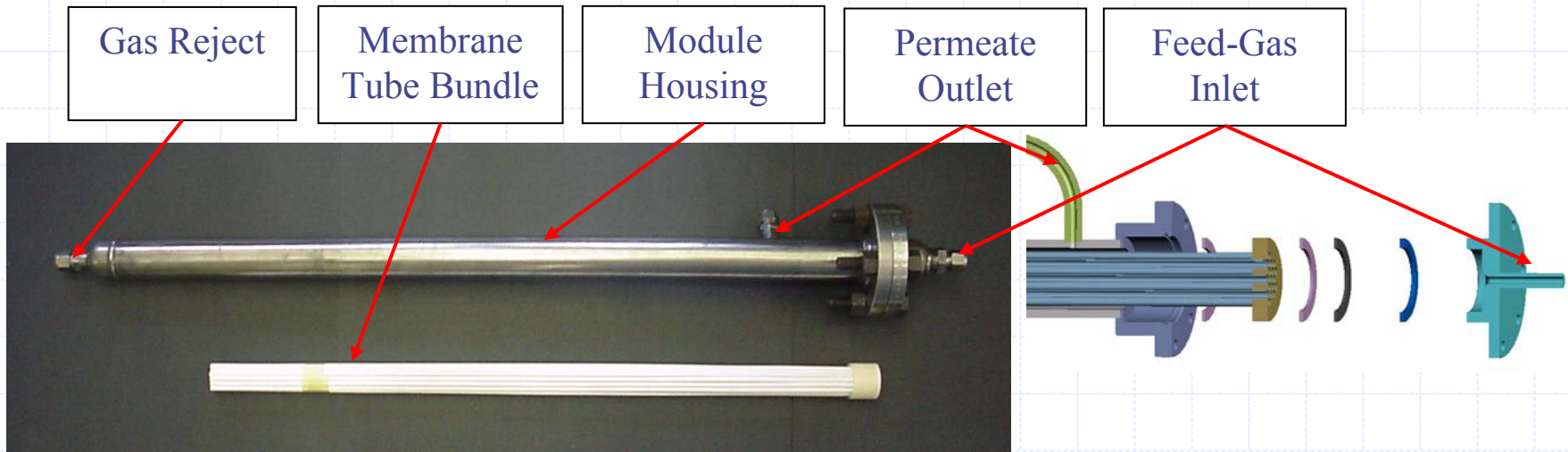
Test Parameter	Coal Results Description	MSW Results Description
Dioxin / Furan	Very Low, 0.005 ng/dscm CDD TEF, 0.002 ng/dscm CDF TEF	Very Low, 0.0035 ng/dscm CDD TEF, 0.0045 ng/dscm CDF TEF
SVOC	Very Low, Almost all non-detects.	Very low. Non-detect on all except the following: 2 methylphenol 0.004 mg/dscm, Benzoic Acid 0.027 mg/dscm, Benzyl Alcohol 0.159 mg/dscm, Bis(2ethylhexyl)phthalate 0.007 mg/dscm, Naphthalene 0.006 mg/dscm
Hydrogen Cyanide	None detected	5 mg/dscm
Hydrogen Sulfide	None detected	None detected
ISO Kinetic Particulate Sampling	Extremely Low; 0.3 mg/dscm. Very good for membrane performance	Extremely Low; 0.4 mg/dscm. Very good for membrane performance
HCL / CL2	None detected	None detected
Ammonia	None detected	None detected

StarCell Hydrogen Purification



StarCell: How It Works

- StarCell Modules are stainless steel housings with Carbon Molecular Sieve tube bundles inside.
- Mixed gas enters through the inlet port and hydrogen permeates through the membrane.
- Hydrogen exits through one exit port and the reject gas exits through another.



M&P Ceramic Membranes



Figure 4. M&P Ceramic Membrane Modules

- *Temperatures > 400°C*
- *Steam sterilizable to > 125°C*
- *Burst pressure > 500 psi*
- *pH resistant*
- *Excellent radiation resistance*
- *Unaffected by solvents, oxidants, etc.*
- *Rugged, reliable, long life > 5 years*

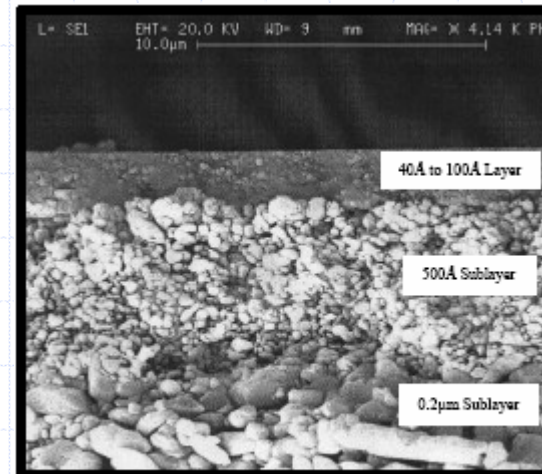


Figure 1. M&P Composite Ceramic Membrane

Table 1. Characteristics of M&P's Ceramic Ultrafilters and Microfilters

<u>Characteristic</u>	<u>Ultrafilters</u>	<u>Microfilters</u>
Active layer:	γ - or α -alumina	α -alumina
Pore Size:	40Å to 0.2µm	0.5 to 3µm

StarCell Baseline Testing

	H2 and CO Separation		
	Stage 1	Stage 2	
Test Gas H2 input:	50%	80%	
Test Gas Temperature (Reject):	50	60	°C
Feed pressure:	102	100	psig
Feed Partial Pressure H2:	51	80	psi
Permeate Pressure:	7	1.2	psig
Permeate side gas composition (%):	80%	96%	
Permeate Partial Pressure H2:	5.6	1.2	psi
H2 Partial Pressure Diff:	45.4	78.8	psi
Membrane surface area:	0.304	0.156	m2
Total gas flow to membrane (lpm):	5.6	2.3	lpm
Total H2 to membrane:	2.8	1.84	lpm
Permeate gas flow:	2.8	1.25	lpm
Recovery rate:	80%	65%	*
Permeance:	0.141	0.085	m3/m2/hr/bar
Flux:	0.64	0.38	scfh/sf/20 psi

* Stage 2 Hydrogen reject to be fed back into Stage 1 Gas Feed.

Note: Flux corrected to 20 psi hydrogen partial pressure differential. No correction has been for temperature which is supposed to be at 400°C for DOE target flux rate.

StarCell PCG Testing

	11/30/05	Two-Stage Hydrogen Purification of PCG			
		Stage 1	Stage 2	Stage 2	
Test Gas H2 input:	35%	35%	52%	52%	%
Test Gas Temperature (Reject):	45	33.5	37.3	38	°C
Feed pressure:	102	101	84.2	85.2	psig
Feed Partial Pressure H2:	35.7	35.4	43.8	44.3	psi
Permeate Pressure:	7.5	8	15.4	12.8	psig
Permeate H₂ Composition(%)	65%	59%	79%	77%	%
Permeate Partial Pressure H2:	4.875	4.72	12.2	9.9	psi
H2 Partial Pressure Diff:	30.825	30.63	31.6	34.4	psi
Membrane surface area:	0.304	0.304	0.156	0.156	m2
Total gas flow to membrane (lpm):	4.8	2.5	1	0.4	lpm
Total H₂ to membrane:	1.68	0.88	0.52	0.21	lpm
Permeate gas flow:	1.5	1.27	0.23	0.18	lpm
Recovery rate:	58%	86%	35%	65%	
Permeance:	0.139	0.119	0.041	0.029	m3/m2/hr/bar
Flux:	0.63	0.54	0.18	0.13	scfh/sf

Note: Stage 2 feed gas was rechecked prior to introduction to the stage 2 membrane. The hydrogen content was measured at 52% rather than the 59 – 63% hydrogen content that was measured directly from the stage 1 permeate. This condition is likely due to preferential hydrogen leakage.

StarCell Test Discussion

- Hydrogen rich gas has been produced from waste material and purified on a commercial scale.
- H₂ Recovery rates of > 80%
- 2 Stage purification from 50% to 96%
- Low gas temperature had a significant impact on membrane performance.
- Membranes performed equally well on PCG and bottled (baseline) gases.
- Testing validated laboratory results on membrane performance.
- Membrane poisoning was minimal on 2 / 3 membranes after >2 months of gas exposure.

2005 Review Comments

- The 2006 presentation focused on the experimental results which was considered a weakness of the 2005 presentation. This testing has established a performance baseline and identified focal areas to be addressed in meeting DOE targets.
- Use of electricity and energy balance:
 - The savings attained by having feedstock flexibility and by using MSW as a feedstock more than offsets the cost of electricity. While the initial scope of the project considered many waste feedstocks, the scope was reduced to focus on the most prevalent feedstock; MSW.

Critical Assumptions and Issues

Gas Production Critical Issues:

- The hydrogen rich gas produced from MSW was clean and suitable for many applications.
- The process uses electricity to operate.

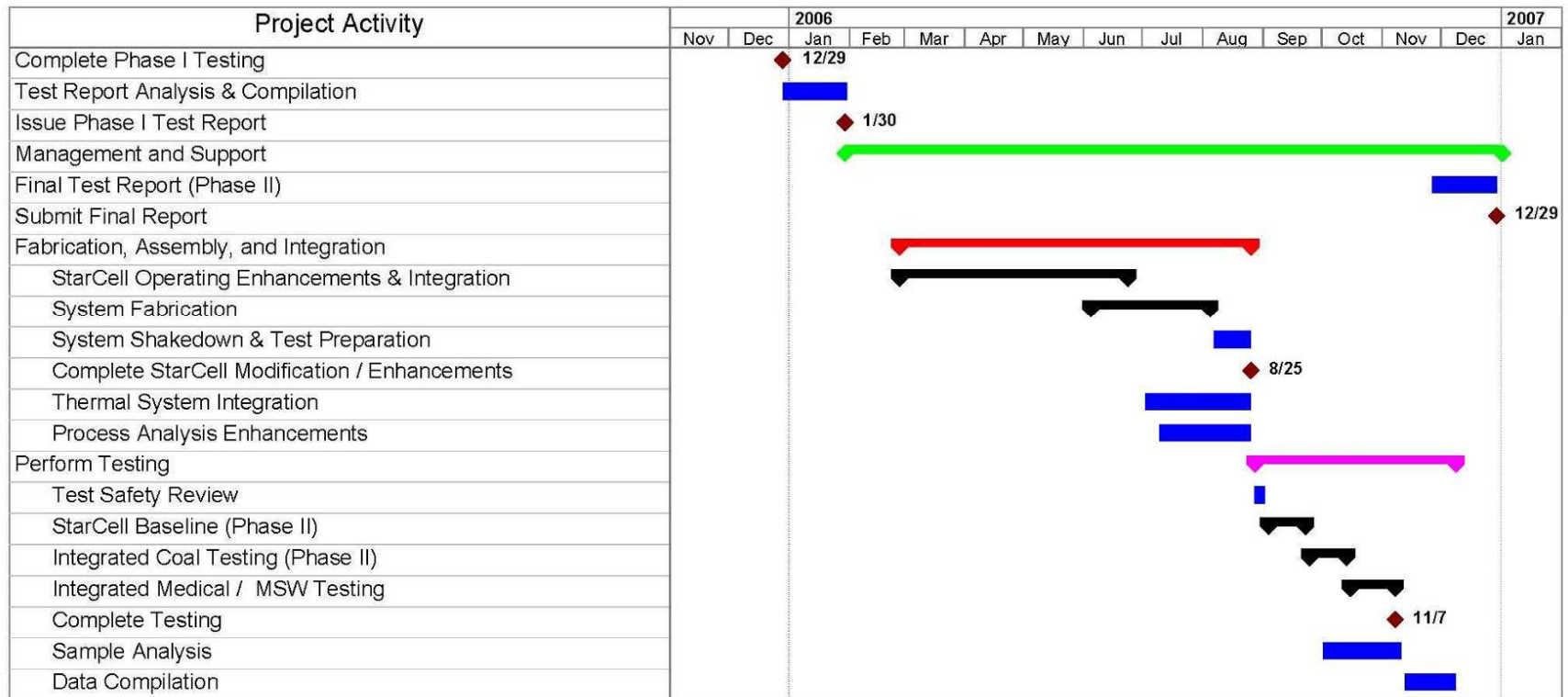
Hydrogen Purification Critical Issues:

- Despite having a cabinet temperature of $\sim 105^{\circ}\text{C}$ and gas heat exchangers, the gas temperature was only $35^{\circ}\text{C} - 50^{\circ}\text{C}$. Low temperatures have an adverse effect on both the membrane flux and selectivity.
- The membrane data collected on the bottled gases was representative of field test performance. This implies both that the membranes will likely be compatible for hydrogen purification from other technologies and that the PCG is suitable for purification by other technologies.

Future Work – 2006 Plan

Startech Environmental Corporation

Hyrdogen Production Project (Phase II)
DE-FGC036-04GO14233



Future Work – Specific Scope

- Incorporate lessons learned from Phase I Testing (Membrane performance & operating parameters)
- Complete StarCell enhancements
 - Increase operating temperature
 - Enhance H₂ yield and quality
 - Implement counter-current flow in modules
- Complete Phase II Testing for MSW and Coal
- Issue Final Report / Technical Findings and Assessment

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Hydrogen Safety: Risks

1. The most significant hazard with this program is the risk of oxygen leaking into the PCG (synthesis gas) stream creating an explosive atmosphere.
2. While this does not pose a significant risk in the Plasma Converter System itself, compressing the PCG containing oxygen could pose risk of an explosion.
3. The most likely accident scenario has to do with the interface of the feed system with the Plasma Converter as it is a fuel in contact with an ignition source.
4. There is also a scenario during shut-down where hot material in the heat exchanger or the particle filter could act as an ignition source if large enough quantities of air leak into the system.
5. In both of these scenarios, a small fire could result in the area of concern.

Hydrogen Safety: Mitigations

1. Oxygen content in the PCG is monitored continuously to ensure that the concentration of oxygen remains well below the LEL of 4%. Our safety review evaluated this potential and the compressors will be enabled to operate only when the oxygen content is less than 1%.
2. Prior to StarCell or Plasma Converter operation, the entire system is purged with nitrogen so that less than 1% oxygen concentration remains in the system prior to introduction of synthesis gas or H₂.
3. All “wetted” parts shall be selected to withstand the temperature, pressure and gas composition for that particular location.
4. Whenever possible, the use of seamless stainless steel tubing and tube bends will be implemented. Where bending is not feasible, compression fittings will be used.
5. Monitoring and controls insure safe operation and fail safe shutdown during upset conditions.